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# Annotated Bibliography of Enabling Technologies for the Small Aircraft Transportation System

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NASA's Small Aircraft Transportation System (SATS) initiative brings together researchers from government, industry, and academia to facilitate the development and implementation of a highly integrated aviation system that relies on advanced small aircraft. SATS is, first and foremost, a technology program designed to augment the capabilities of light aircraft. Successful development and deployment of new technologies and the integration of existing technologies into small aircraft will drive the program towards its ultimate goals of substantially reducing travel times for air travelers. Travelers will be able to utilize reliable and affordable SATS aircraft to avoid congested airline hubs and easily reach thousands of general aviation airports that are generally underutilized.

Successful SATS implementation relies on the development of aircraft that can take full advantage of new on board technologies as well as changes in the existing airspace infrastructure. Early generations of SATS vehicles will utilize technology to improve reliability and safety in small aircraft operations, while future generations of owner-operated vehicles will utilize technology to provide affordable and accessible personal transportation. Computerization and automation will facilitate the development of the aircraft and the system. Integrated computer networks will provide airborne traffic, current weather, and all other needed information in real time. Technology will allow for increased autonomy within the airspace system and preclude the need for traditional air traffic control, thus reducing the need for costly human dependent systems.

The following collection of research summaries are submitted as fulfillment of a request from NASA LaRC to conduct research into existing enabling technologies that

support the development of the Small Aircraft Transportation System aircraft and accompanying airspace management infrastructure. Due to time and fiscal constraints, the included studies focus primarily on visual systems and architecture, flight control design, instrumentation and display, flight deck design considerations, Human-Machine Interface issues, and supporting augmentation technologies and software.

This collation of summaries is divided in sections in an attempt to group similar technologies and systems. However, the reader is advised that many of these studies involve multiple technologies and systems that span across many categories. Because of this fact, studies are not easily categorized into single sections. In an attempt to help the reader more easily identify topics of interest, a SATS application description is provided for each summary. In addition, a list of acronyms provided at the front of the report to aid the reader.



## Acronyms and Abbreviations

AGL	Above Ground Level	IFR	Instrument Flight Rules
AHRS	Attitude and Heading Reference System	ILS	Instrument Landing System
ASAS	Airborne Separation Assurance System	INS	Inertial Navigation System
ASP	Aviation Safety Program	LWIR	Long Wave Infrared
ATM	Air Traffic Management	MFD	Multi Function Display
AWIN	Aviation Weather	MMW	Millimeter Wave
CDU	Control Display Unit	NAS	National Airspace System
CFIT	Controlled Flight into Terrain	NED	National Elevation Data
COTS	Commercial off The Shelf	ND	Navigation Display
CWIN	Cockpit Weather Information	PMMW	Passive millimeter Wave
DEM	Digital Elevation Model data	PFD	Primary Flight Display
DOF	Degree of Freedom	RTO-DB	Real-Time Onboard Database
DPGS	Differential Global Positioning System	RSC	Rockwell Science Center
ESVS	Enhanced Synthetic Visual System	SAR	Synthetic Aperture Radar
FAA	Federal Aviation Administration	SATS	Small Aircraft Transportation System
FLC	Fuzzy Logic Controller	SVD	Synthetic Vision Displays
FMCW	Frequency Modulated Continuous Wave	SVS	Synthetic Visual System
GPS	Global Positioning System	SVIS	Synthetic Vision Information Systems
HITS	Highway in the Sky	SWIR	Short Wave Infrared
HMD	Helmet Mounted Display	TAWS	Terrain Awareness and Warning Systems
HMI	The Human Machine Interface	TFM	Traffic Flow Management
HUD	Heads Up Display	USAF VRD	United States Air Force Virtual Reality Display
		VFR	Visual Flight Rules
		WINCOMM	Information Weather Information Communications

## **Flight Deck Design and pilot display systems**

Behringer, R., McGee, J., Sundareswaran, V., & Vassiliou, M. (2000) A system for synthetic vision and augmented reality in future flight decks. *Society of Photo-Optical Instrumentation Engineers (SPIE) Proceedings*, 4023, 81-86.

**SATs application:** Use of ESVS systems to permit flying VFR in conditions that would normally require IFR procedures. HUD, externally mounted video feed camera connection overlaid on data base generated visual system, combined with avionics symbology. COTS software data base usage and description of supporting architecture.

**Summary:** This paper describes a system that consists of an external camera producing real time intuitive images that is overlaid on a synthetic visual system generated by a registered data-base. The augmented field of view is projected either to a Heads-up Display (HUD), Helmet Mounted Display (HMD) or Imaging Goggles. HUD is preferred to replicate pilot VFR flight scan characteristics. Camera orientation is determined by an inclinometer and a magnetometer. Positioning information is acquired from GPS.

ARscape is software developed by Rockwell Science Center (RSC) for general multi-modal display based on 1 arc sec. (approx 30m) resolution of National Elevation Data (NED). Terrain data base created using Terra Vista software from TerreX (registered).

ARscape is a Microsoft Visual C++ application using VTree API from CG2 for rendering. VTree is platform independent (NT or UNIX) 3D graphics kit built on top of OpenGL. ARscape system is implemented on an SGI 320 NT workstation. External camera is affected by severe weather, degradation of visual image in fog and rain will occur.

Sadjadi, F., Helgeson, M., Radke, J., & Stein, G. (1999). Radar synthetic vision system for adverse weather aircraft landing. *Institute of Electrical and Electronic Engineers (IEEE), Transactions on Aerospace and Electronic Systems* (0018-

**SATS Application:** Enable VFR type flight in IFR conditions.

**Summary:** SVS & ESVS system using runway and approach synthetic developed terrain via a 35Ghz real time imaging radar feed into a HUD. Both field (tower) and aircraft (Gulfstream 2) tests were conducted in actual Cat III weather conditions. Tests results indicate a performance advantage of using a HUD over Look-Down System (HDD) in marginal weather conditions. System developed under Synthetic Vision System Technology Demonstration (SVSTD) program sponsored by the FAA and USAF using 35 GHz mmw radar to aid aircraft takeoff and landing in adverse weather conditions. The SVS prototype used in this study was a non-coherent, low duty cycle pulsed radar that produced camera-like images at over 10 frames per second. The system components consist of an electro-mechanically scanned antenna, transmitter, millimeter wave integrated circuits (MIMIC) receiver, display processor, heads up display and supporting instrumentation. Antenna sweep is vertical fan-beam, from left to right with over 30 degrees of azimuthal field of view at sweep rate of approximately 10.5Hz. The HUD was provided by GEC avionics, displaying a RS -170 raster image, overlaid with guidance stroke symbology. Symbology provided the pilot with critical flight parameters (altitude, airspeed, heading, distance to runway, etc.) ILS glide slope references, and approach/flare guidance cues. Tower tests yielded range of over 3000m in clear weather, 1000m in fog and medium rain. In heavy rain radar usable imagery was approximately 2000m. However, during this heavy rain, the human eye is adequate for aircraft landing without the imager. Generally the imager performed adequately under all conditions for which the

human eye was inadequate. Conversely, the conditions under which the radar imager was inadequate did not require aid to human vision. Thus the advantage of using a HUD instead of a look down display is realized. Experienced pilots were capable of executing Cat III approaches below 200' AGL DH using the synthetic visual mmw assisted system.

Mehler F. E. (2000). An integrated navigation, flight guidance and synthetic vision system for low level flight. *Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings)*, 4023, 72-80.

**SATS Application:** Study of 4-D Visual and Navigation Systems for Controlled Flight into Terrain. Visual system comprised of both HUD and HDD presentation. Navigation supported by mission computerized preloaded data base supported by data linked in-flight updates. SIMM and Flight Test conducted. SVS approach conducted to CAT II minimums by experienced military test pilots. Contains depictions of SVS HDD, flight-path information and symbology. Auto-throttle control systems.

**Summary:** The flight guidance system consisted of a trajectory generator, an autopilot and system moding module. Tests were conducted in two phases, manual and auto-piloted. Display components consisted of a HUD and HDD which were used for all flight information display of flight director and pre-planned routes. HDD was split into three portions: a perspective display, a vertical situation display, and a navigation display. Both perspective and navigation displays have SV in 3D view of surrounding terrain and features. Critical terrain at same altitude was color coded red for increased pilot awareness. Low level flights were fulfilled without the need of a differential-based GPS (conducted at 1000' agl). 4-D flight was only possible with the use of auto-pilot system. With GPS available approaches were flown to CAT II minimums, non-GPS approaches

were flown to CAT I minimums. This study additionally contains examples of SVS HDD navigation depiction and symbology.

Delgado, F., Altman, S., Abernathy, M., & White, J. (2000). Virtual cockpit window for the X-38 crew return vehicle. *Society of Photo-Optical Instrumentation Engineers (SPIE) Proceedings*, 4023, 63-70.

**SATS Application:** Virtual cockpit window-all-weather, day/night awareness display.

LandForm Flight Vision system uses five different resolutions of digital topography to model flight.

**Summary:** This visual display design incorporates a perspective viewpoint controlled to six degrees of freedom (6 DOF). Typically, the data is obtained from embedded GPS inertial navigation systems on board aircraft. The data is either used onboard, transmitted and viewed live from the ground, or recorded and replayed as a flight track at a later time. Visual display input is augmented by an aircraft mounted camera providing perspective that represents any point in the 3-D virtual environment, and can rotate about 3 axes to any orientation. Visual output incorporates land surface shape, textures or draped imagery including digital maps, satellite and aerial imagery, static objects such as landing zones and obstacles, man-made or other transient objects, including aircraft, and heads-up displays which project important situational information. Architecture is publicly available. Geotiff image format is available for geo-referenced imagery, USGS and NIMA formats are available for Digital Elevation Models. LandForm script can be used for scene description format and AASCII comma-separated variable format is available for flight track.

Lippert, T. M. (1998). Virtual retinal display technology. *Institute of Electrical and Electronics Engineers (IEEE), Inc Proceedings*. 1, D35-1 to D35-6.

**SATS Application:** Visual technology for SATS, HMD, goggles, light weight, cost savings over traditional displays, higher resolution than MFD, LED

**Summary:** Microvision reports technology to support functional head or helmet mountable 1280 X 1024 pixel, full color, binocular VRD system. Design employs a modulated, low power beam of light to paint an image directly onto the retina of the viewer's eye. VRD typically consists of three units: 1) system unit- the drive electronics and light source module, 2) interconnect cable-optical fibers and electrical conductors between the system unit and display unit and 3) display unit-HMD or Head mounted, containing scanner assembly and viewer optics. This display can augment or replace traditional display scope presentations (flight performance, terrain, HITs).

**Crossover applications:** This technology is applicable to multiple fields; Defense and public safety, Healthcare, Industrial, Wireless Communications, Consumer electronics. VRD in this form obtainable at reasonable costs, consume very little power, provide high quality imaging without encumbering or blocking vision.

System embeds (COTS) head and eye-tracking capability into visually-coupled HMD systems.

**Crossover applications:** Image guided surgery in especially delicate procedures like spine and brain operations

Fay, D. A., Waxman, A. M., Aguilar, M. Ireland, D. B., Racamato, J. P., Ross, W. D. Streilein, W. W., & Braun, M. I. (2000). Fusion of 2-/ 3-/4- sensor imagery for visualization, target learning and search. *Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings)*, 4023, 106-115.

**SATS Application:** Research of imagery gathered from multiple sensors to enable night vision capability as input to synthetic visual flight display

**Summary:** This research involved work on methods for fusion of imagery from multiple sensors for night vision capability. The fusion system architecture is based on biological models of spatial and opponent-color processes in the human retina and visual cortex.

The dual-sensor fusion system involved in this study combines imagery from either a low-light CCD camera (developed by MIT Lincoln Laboratory) or a short-wave infrared camera (developed by Sensors Unlimited, Inc.) with thermal long-wave infrared imagery (from a Lockheed Martin microbolometer camera). The real-time dual-sensor system worked with SWIR and LWIR cameras. Examples are presented for an extension of the fusion architecture to include imagery from all three of these sensors as well as imagery from a mid-wave infrared imager. This study has produced a new real-time color night vision system based on commercial DSP boards for fusing SWIR and LWIR imagery.

The real time fusion architecture, based upon a single nonlinear image processing operator, was adapted to process imagery from more than two sensors. Authors, in related work, have used multi-sensor fusion systems to combine and exploit remotely sensed multi-spectral, synthetic aperture radar, and hyper-spectral imagery in the context of 3D site models.

**Crossover applications:** automobile and truck and maritime vessels

Behringer, R., Tam, C., McGee, J., Sundareswaran, V., and Vassiliou, M. (2000). A system for synthetic vision and augmented reality in future flight decks. *Enhanced and Synthetic Vision 2000*, J. G. Verly (ed.). Proceedings of SPIE, 4023, 81-86.

**SATS Application:** Synthetic visual display design, virtual *VFR flight* during instrument conditions, augmented reality displays overlay real world objects on virtual view.

**Summary:** Rockwell Science Center produced an augmented human-computer interface technique to produce enhanced situational awareness in future flight decks. System would use a camera to grab video images of real world terrain and conditions which are then overlaid on computer generated visual information. In this system the pilot would be able to relate the generated information overlay to real objects in the world and match the overlay for accuracy with the computer generated synthetic field. This would enable the pilot to detect navigation discrepancies and computer visual inconsistencies, ensuring safety and en route navigation and approach accuracy. If visibility is sufficient, the overlay can be used to update and improve navigation by matching real world points with the data-base. Augmented visual information can be presented through a HUD to the pilot providing easy reference and comparison. Orientation of the camera is obtained from an inclinometer and a magnetometer, while position is supplied by GPS.

Hammer, M., Mucke, S., & Mayer, U. (1998). Development of a 3D stereoscopic flight guidance display. *Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings)*, 3364, 103-114.

**SATS Application:** Determine best ergonomic design for visual flight display systems using HDD. Tests between 2D and 3D visually displayed terrain and flight performance data. Study describes Terrain and flight data symbology presentation on SVS display. User preferences, compiled from aviation and non aviation experienced test subjects, is presented.



**Summary:** This study focused on stereoscopic perspective light guidance displays on head down displays. It further investigated the binocular field of view, the basis for stereoscopic vision. Stereoscopic symbology provides situational awareness relative to terrain and other aircraft in intuitive way not currently used in present flight deck data displays. Depth information is produced by using parallax between the left and right eye. This laboratory study used a Silicon Graphics Onyx RE2 and "21" monitor. The stereo system used Chrystal Eyes shutter lenses with infrared synchronization. Flight simulations were performed with an active side stick coupled to the workstation. A total of 29 subjects under the age of 40 took part in experiment. The test group consisted of aviation and non aviation experienced personnel. Flight testing consisted of maneuvering an aircraft through a series of flight navigation tunnels (highway in the sky). Four different visual textures of tunnel walls were tested. Track error was lowest in heaviest textured visual representation. Overall stereoscopic perception decreased track error by 25-30% over monoscopic presentation. Pairing aircraft performance scales with flight predictor information focuses operator attention better than locating flight information separately.

Zellers, S. (2000). Description of a database server architecture for synthetic vision system applications. *Entering the second century of powerful flight; Proceedings of the 19<sup>th</sup> Digital Avionics System Conference (DASC)*, Philadelphia, PA, Oct. 7-13, 2000. *Institute of Electrical and Electronic Engineers*, 1, 2.C.2-1 to 2.C.2-6

**SATs Application:** Computer architecture and server data base design supporting synthetic visual systems.

**Summary:** An aeronautical database server subsystem for synthetic vision systems refers to an onboard unit in the aircraft that stores and manages a layered database to support

SVIS (Synthetic Vision Information Systems) applications. The general database server architecture is composed of four integrated components: the server processing computer, storage medium, geo-referenced database, and the system interconnects. This paper presents a proposal for server architecture and discusses system design choices confronted in the assembly of a prototype at Rockwell Collins.

Sachs, G., Dobler, K., & Hermle, P. (1998). Synthetic Vision Flight Tests for curved Approach and Landing. Institute of Electrical and electronics Engineers, Inc (IEEE) Transactions on Aerospace and Electronic Systems, 0-7803-5086-3, E51-1-E51-8.

**SATS Application:** Integrated visual synthetic approach system incorporating aural altitude reporting and visual tunnel approach information, includes supporting airport architecture.

**Summary:** This paper reports flight testing of a computer SVS comprising guidance information that produces a 3 dimensional pictorial presentation of the outside world and a perspective flight path display for curved trajectory following (guidance tunnel). A precision navigation system supplied the synthetic vision computer with altitude.

Positioning data was supplied by differential global positioning and inertial sensor navigation data. Wide-Area-DGPS mode was used in non-terminal flight test areas and a Local-Area-DGPS mode was applied during approach and landing in conjunction with a ground reference station installed at the airport. A high degree of navigation performance was achieved through the coupling of differential global positioning and inertial sensor systems producing integrated precision navigation architecture. Flight testing was initiated at approximately 350 meters above ground. The flight task was to follow a flight path based upon an ILS glide slope. SV information was presented to accomplish this

task and acoustic information was provided to the pilot, indicating actual height above the ground. Specified trajectory for the curved approach was presented as a visual guidance tunnel.

Griffin, M., Pera, L., & Cabrera, L. (2001). Operational assessment of the tactile situational awareness system. *Report 18<sup>th</sup> Flight Test Squadron*, 320 Tully Street, Hurlburt Field, Florida 32544-5446 Air Force Special Operations Command, United States Air Force.

**SATs Application:** Augmentation system for visual displays, to enhance safety, counteract motion sickness, increase situational awareness and reduce pilot workload.

**Summary:** TSAS uses sense of touch to provide spatial orientation to crewmembers or passengers. This system takes data directly from current aircraft systems, processes it and then relays designated information to the individual using miniature tactile stimulators, termed tactors. TSAS involves wearing a suit composed of either pressure bladders or electronic stimulators. The TSAS suit provides 3-axis aircraft movement information via aircraft systems directly to the wearer. Wearer experiences tactile sensations corresponding to actual aircraft movement counteracting inner ear false movement input. TSAS experimental tests were conducted in a CV-22 simulator and flight testing was performed in helicopters. TSAS is currently in test and development stages.

## **Synthetic Vision Flight Test**

Barrows, A. K., Alter, K. W., Jennings, C. W., & Powell, J. D. (1999). Alaskan flight trials of a synthetic vision system for instrument landings of a piston twin aircraft. *The International Society for Optical Engineering, (Proceedings of SPIE)*, 3691, 98-106.

**SATS Application:** Flight trials of low cost synthetic (3-D) visual and navigation systems (tunnel-in-the-sky). Tests consisted of 37 hours of flight trials including a 162 landing/approaches, 9 pilots, 2 aircraft and 6 airports (3 in Alaska). Computer architecture based on low cost commodity 486 and Pentium processors for display, using differential GPS for navigation.

**Summary:** This trial applied enabling technologies to a low cost system retrofitted to a Piper Dakota single piston Aircraft and a twin piston Beechcraft Queen Air. Basic display format was a FOV 40 degrees horizontal by 50 degrees vertical. Approach and missed approach paths were depicted as a series of 100M wide by 60M tall "hoops" spaced at 200M intervals. The Flight Predictor was shaped like a circle with wings that displayed aircraft predicted position (based on current position, velocity, and lateral acceleration estimated from bank angle) 3.5 sec into future. Differential GPS (DPGS), supplied primarily by Stanford's Wide Area Augmentation System prototype, used the FAA National Satellite Test Bed network of reference receivers (display vertical accuracy 2M 95% accuracy). The operating system was originally a 486 laptop DOS, upgraded to ruggedized Pentium PC which ran at 90 MHz on Windows NT. Tests were initially flown at Moffett field in California, then overlays to IFR approaches were conducted at Juneau, Sitka, and Petersburg, Alaska. Pilots were able to fly the display well with virtually no training prior to flight, save an explanation of the display symbology. Pilots learned to fly

the Tunnel Display with almost no training. Student pilots were soon able to fly instrument approaches better than most instrument-rated pilots.

Williams, K. W. (2000). Impact of aviation highway-in-the-sky Displays on pilot situation awareness. *Department of Transportation and Federal Aviation Administration (DOT/FAA/AM-00/31) Final Report*, October.

**SATS Application:** Hits Symbology/Pathway Visual Display impact on pilot situation awareness (SA): Task complexity in regard to use of Heads-up display and Heads-down Displays was tested. Participants were 36 pilots that held current private pilot or a higher rating, career pilot time averaged 830 flight hours.

**Summary:** The study was designed to provide information on the effects for different pathway format and guidance cues on the ability of pilots to establish aircraft on visually displayed navigation pathways. In addition, while performing this task, the ability of pilots to locate other aircraft visually was measured. Testing was conducted in a simulated Piper Malibu, SE, high-performance aircraft with retractable landing gear. The simulator was fitted with conventional analog controls including rudder pedals, throttle, gear, flap and trim controls. Pilots flew six scenarios, lasting 9 and 12 minutes each. 76% of the pilots tested believed that goal post displayed navigation information was easier to acquire than alternative paving stone for the flight pathway. For in flight guidance information to achieve pathway acquisition, 72% of pilots thought that the follow-me airplane symbology made pathway acquisition easier. Task complexity was major factor influencing to the pilot's ability to acquire other traffic. The greater task complexity, the lower the ability to spot traffic. In general older pilots appeared to experience a greater degree of difficulty in using displays and HITS information. Pathway depiction proved to be not as important as during testing as simple orientation and practice with the display.

Task complexity has a more powerful effect on the ability to focus attention outside of the cockpit, than does display novelty. Author recommends placement of HITS information on HUD allowing pilot to simultaneously maintain both visual contact with display and at least partial focus outside of the cockpit.

## **Man Machine Interface-Flight Deck Design considerations**

Kubbat, W.J., Lenhart, P.M. and von Viebahn, H. (1998). 4D flight guidance displays, A gate to gate solution. *Institute of Electrical and Electronic Engineers (IEEE)*, (0-7803-5086-3), E55-1 to E-55-8.

**SATS Application:** Design considerations for 4 Dimensional visual flight displays and supporting navigation displays.

**Summary:** The challenge to increase air traffic capacity and at the same time improve safety and efficiency can only be achieved if future cockpit instruments are able to provide pilots with the necessary spatial situational awareness during any phase of flight. The means to produce this situational awareness is synthetic vision. A graphical data base, a precision navigation system and the 4D flight guidance displays driven by a symbol generator, capable to render 3D images, form the pillars of this studies synthetic vision system. The Human machine interface (HMI) in this proposal consists of two perspective displays complementing one another. The Primary Flight Display (PFD) incorporates a synthetic insight out view, while the Navigation Display (ND) is characterized by a synthetic 'birds eye view'. By providing not only flight guidance, but also taxi and traffic information the two displays will support the pilot from gate to gate. The three pillar architecture system concept presented for system support consists of (1) data base supplemented by real world input; (2) navigation input; and (3) the 4D displays.

Trujillo, A. C. (undated). Response times in correcting non-normal system events when collocating status, alerts, and procedures, and controls. *NASA Langley Research Center Report*, LaRc Technical Library.

**SATS Application:** Pilot Display Design and testing: grouping of information and control elements into single display to improve workload, controlling of non-normal

events in aviation environment, while minimizing costs, weight, complexity of instrumentation displays.

**Summary:** By using CRTs and improved computing power, it is possible to combine multiple display warning and procedure systems into a single display. This research was conducted to determine which display functions should be collocated in order to better perform and respond to simple non-normal events. Display configurations were tested in five gradations ranging from being grouped on one screen to having displays and control functions dispersed in various combinations in up to three displays. Results indicated that (1) combining status and alert/procedure information and controls on one display information on one display or (2) combining status and alert/procedure information on one screen and separating out controls to another area may improve performance over systems that keep this information separated. Test group: Half were commercial glass-cockpit line-pilots; the other half had no piloting experience. Presents wide range of industrial applications outside of aviation.

Arbuckle, P. D., Abbott, H. H., Abbott, T. S., and Schutte, P. C. (1998). .  
Future flight decks. *21<sup>st</sup> Congress International Council of the Aeronautical Sciences-Paper Number 98-1.9.3. September 13-17, 1998 Melbourne, Australia.*

**SATS Application:** Flight Deck Configuration and Design using human-centered light deck design methodologies incorporating commercial and/or entertainment-driven technologies.

**Summary:** The current airspace system relies almost exclusively on humans as control elements. Ground-based control personnel are primarily located in system outer loops and pilots located in system inner loops. Given that a fully automated system of control and flight is not possible, a system containing both machine and human control elements will



be required. The FAA model for aviation accidents is presented in this study, as well as three strategies for accident prevention. Factors that influence flight deck design changes consider differences between requirements and objectives. Historical system and component certification considerations are analyzed. Human-Centered Flight Deck Design components are delineated; (1) Human-centered principles maintain that the human operator must be in command. Automated functions, including air traffic management automation, must never remove the pilots from the command role, either implicitly or explicitly; (2) NASA human-centered design philosophy assumes flight crews will remain integral component of flight deck design for the foreseeable future. Flight decks should always support various pilot roles for mission completion; (3) Function allocation and involvement is an important part of flight deck design. The pilot should be involved in actions/decisions that have significant consequence in the overall mission. Actions and decisions that are relatively deterministic, time constrained, tedious or repetitious should be minimized; (4) Flight Deck Mission Categories combine human-centered design principles with systems-oriented approach. Designs must accommodate four levels of mission management: flight management, communications management, systems management, and task management; (5) Task-oriented Display Design should be used to develop task-oriented instrument/aircraft system displays; (6) Fault management is real time fault management integrating three elements: operational levels (aircraft mission, physical aircraft in aerodynamic environment, aircraft systems), cognitive levels of control (skill-based, rule-based, and knowledge based behaviors).

Helmetag, A., Halbig, C., Kubbat, W., & Schmidt, R. (1999). Cognitive mapping based on synthetic vision? Conference on Enhanced and synthetic, Orlando, FL, Apr. 5, 6, 1999. *Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings)*, 3691, 48-56.

**SATs Application:** Development of data bases supporting SVS display and navigation.

**Summary:** Analysis by the authors determined that 'Controlled flight into Terrain' was caused by insufficient pilot awareness. The focus of this study was to develop the design of a SVS system that could be intuitively understood by the pilot, thereby increasing situational awareness and eliminating the historical CFIT hazard. The researchers approach incorporated the detection of potential ground collision through the monitoring of a perspective Primary Flight Display. This display is based on the psychological point of view that accounts for the expansion of objects in the visual flow field. This concept is supported by a navigational display design that enables conflict resolution to be quickly worked out mentally. Cognitive mapping of terrain characteristics can be supported in one of two ways: realism is increased when typical landmarks are displayed as features or satellite images or terrain data is depicted as topographic ridge and contour lines.

Centrally developed and maintained data bases could be used for simulator training as well as real world in-flight visual display and navigation.

Sinai, M. J., Deford, J. K., Purkiss, T. J., & Essock, E. A. (2000). Relevant spatial frequency information in the texture segmentation of night-vision imagery. *Society of Photo-optical Instrumentation Engineers (Proceedings of SPIE)*, 4023, 116-126.

**SATS Application:** Man-machine design considerations: real time augmentation of SVS.

Night vision imagery using low-light, infrared, and monochrome sensors to display visual field

**Summary:** This research investigated the type of spatial structure present in nighttime imagery that is perceptually relevant for human observers to be able to perform texture-based segmentation of real world scenes. Three psychological tasks were developed to evaluate the performance of the nighttime imagery. The test imagery consisted of scenes obtained from an image-intensified low-light CCD, a long-wave infrared sensor and a monochrome sensor-fusion. For one task, performance fused imagery proved best, but for two tasks, performance with fused imagery was not improved (compared to performance with IR imagery). Spatial filtering of the scenes and further testing revealed that the mid spatial frequencies (1-4cpd) were more critical in determining performance than either the low or high frequencies. Further analysis of the scenes revealed a strong relationship between power and performance, where scenes with more power (especially at the middle frequencies) supported better performance. The principle implications of this research are that performance depends on power in middle frequencies for low-level visual tasks and that fusion algorithms may be improved if this is taken under consideration.

## **Flight Control Systems**

Beringer, D. B. (no date). Performance-controlled systems, fuzzy logic, and fly-by-wire controls: Revisiting applications to general aviation. *Proceedings of the 43<sup>rd</sup> annual Meeting of the Human Factors & Ergonomics Society*, no date, NASA Langley Research Center Library.

**SATS Application:** Advanced automated flight control system.

**Summary:** Use of Fuzzy Logic Controller (FLC) to simplify the manual flight control systems in general aviation aircraft. SIMM testing evaluated 24 high time, low-time, student and non-pilots using FLC, HITS symbology and a HDD Display. Data was collected in an AGARS configured Piper Malibu with a HITS format navigation display, Flight path information used a follow-me airplane symbol and velocity vector on the copilot's side of the instrument panel. Tasks required the participant to take off, establish a climb to intercept a 3-D depicted course line and follow the command guidance indicator by aligning the aircraft velocity vector with the follow-me airplane. Tests were performed in two sessions: session one was flown with a back-loaded yoke and separate power controls. Session two was flown using the FLC system. Use of the FLC system produced an approximate 3:1 reduction in control movements in comparison to the conventional control system. This study also includes a discussion of concerns for using the FLC as the critical flight system, options for flight control system backup, system reliability requirements. The analysis also included the possibility of having to allow for slightly less reliable FLC, employment of a stand-by mechanical linkage system and the costs associated with training and operating two control systems.

Stewart E.C (1994). Piloted Simulation Study of Advanced Controls and Displays for Novice General Aviation Pilots. 32<sup>nd</sup> Aerospace Sciences Meeting & Exhibit, January 10-13, 1994 / Reno, NV. *AIAA paper 94-0276 NASA Langley Research Center.*

**SATS Application:** Combination of Advanced Control System and Visual System that enable non pilots and experienced pilots to perform complex take offs, landings, and navigation in CAT III instrument conditions. Comparison of performance between HUD and HDD.

**Summary:** Fly-by-wire technology previously developed for military and commercial aviation is of much greater benefit to novice pilot. These technological improvements could drastically decrease time and money required for pilots to under take flight operations in instrument conditions. NASA developed a control system named "Easy-to-fly" (E-Z fly). This system has three main cockpit controls (longitudinal wheel, throttle, and lateral wheel). A rudder is used to control side slip angle, but the rudder is only a factor in cross wind landings. The control design consists of four major control paths. The longitudinal wheel commands vertical speed, using proportional wheel commanded vertical speed using proportional plus integral (PI) forward paths. Gain scheduling is a function of airspeed and dynamic pressure used in conjunction with pitch attitude and pitch rate feedback to provide proper damping. Throttles command airspeed using PI control law. Feed-forward path is also employed to reduce engine transients after initiating large changes in the commanded airspeed. HITS information was displayed on wide-angle (36 degree by 20 degree) head-ups color presentation that was superimposed on the simulator's normal real-world visual system. This flight control system was evaluated by using a combination of non-pilots and pilots in the performance of take off, landings and in flight maneuvers. The simulated aircraft was twin-engine, possessing a dual 300 HP

turbo-charged rating and having a gross weight of 6200 lbs with a 40-foot wingspan. Test conditions resulted in all non-pilots and pilots flying approaches in 200-250 feet agl (above ground level) weather conditions to controlled touchdowns. Findings were that a head-up display configuration was preferable to the head-down display.

Stewart, E.C., Ragsdale, W.A., & Wunschel A.J. (1988). An evaluation of automatic control system concepts for general aviation airplanes. Presented at the 1988 Atmospheric Flight Mechanics Conference. Minneapolis, MI. Source: *AIAA Paper No. 88-4364*

**SATS Application:** Early study of automatic flight control systems in general use aircraft.

**Summary:** Detailed description of considerations involved between conventional flight control systems and automated control systems in simplifying flight characteristics of small aircraft for novice aviators. Preliminary simulator study of five automatic control systems for general aviation airplanes was conducted. A simple airspeed command system, a pitch attitude command system, a vertical speed command system, and combinations of these individual systems were studied. The aircraft was flight modeled as a twin engine light aircraft weighing 6200 pounds with 600 Hp and 40 foot wingspan. The best control system was one in which the cockpit throttle lever angle commanded airspeed and the longitudinal wheel position commanded the vertical speed. Uses decoupled airspeed and vertical speed responses in cockpit controller inputs. Cockpit throttle lever command only airspeed responses, and longitudinal wheel position commanded only vertical speed responses. System significantly reduced pilot workload throughout an entire mission of the airplane from takeoff to landing. Changing flap position or maneuvering in steeply banked turns did not affect aircraft vertical speed or

airspeed. Conducted simulated flight maneuvers down to instrument conditions of 200 feet. Flared landings were conducted. Works loads via this system were significantly lower than when convention fight control systems were employed.

## **Air-Ground Traffic Management (ATC/DAG-TM)**

FAA/Eurocontrol. (2001). Principles of operation for the use of airborne separation assurance systems. Action Plan 1: *FAA/EUROCONTROL COOPERATIVE R&D*, dated 19 June 2001.

**SATS Application:** Integrated Air Traffic Management system, distributing airborne spacing and separation responsibilities between flight crews and ground control.

Enhancing autonomy of individual flight operations, enabling increased traffic volume supporting SATS program.

**Summary:** Document serves as guideline for international research community to focus on policy, technical and safety issues prior to the implementation of any Airborne Separation Assurance System (ASAS). The ASAS is an aircraft system that enables the flight crew to maintain separation of its aircraft from one or more other aircraft, and provides flight information concerning surrounding traffic. ASAS application is established through a set of operational procedures for controllers and flight crews using the capabilities of the ASAS to meet clearly defined operational goals. ASAS applications are heavily dependent upon aircraft systems. Changes to present aircrew and controller responsibilities require rigorous safety and implementation analysis. Document delineates expected benefits from use of ASAS that includes safety benefits (Safety Awareness, Automation, Guidance presented directly to flight crew), user flexibility and flight efficiency (support ability of users to fly preferred routes and trajectories-enhancing fuel and time efficiency), increased throughput/capacity benefits, and environmental benefits (optimum profiles support reduction in flight time and subsequent exhaust emissions and noise).



Green, S. M., Karl D. Bilimoria, K. D., & Ballin, M. G. Distributed air-ground traffic management for en route flight operations. *AIAA Guidance, Navigation, and Control Conference*, 14-17 August 2000, Denver, CO. AIAA 2000-4064

**SATS Application:** Presents NASA's concept for en route Distributed Air-Ground Traffic Management (DAG-TM). This is a detailed demonstration of the Free Flight concept to support NASA's long term research to enable mature-state Free Flight within the National Airspace System.

**Summary:** Near-term National Airspace System (NAS) modernization efforts focus on the evolutionary enhancement of Air Traffic Management (ATM) Systems. DAG-TM proposes the enhancement of NAS operations through procedural and technical integration of airborne, flight planning, and ATM systems. DAG-TM is human-centered. It is an operational concept that minimizes the impact of current Air Traffic Management (ATM) constraints through the leveraging of new procedures, automation aids, and information sharing, and supporting technologies. DAG-TM spans all phases of flight within the NAS to include the operational needs of airline, general, and military aviation. Mixed aircraft equipage within this DAG-TM structure is assumed to be the norm and airspace is assumed to be accessible to virtually all user classes. This paper describes four en route concept elements: two of which define possible modes of operation, enabling user flexibility to plan and fly user-preferred 4D trajectories and two that employ concept elements of collaborative Traffic Flow Management (TFM) operations to minimize user impact of dynamic traffic congestion at the destination or in en route airspace.

## **Flight Management Systems**

Abbott, T. S. (undated) . The evaluation of two CDU concepts and their effects on FMS training. *NASA Langley Research Report*, undated. NASA Research Center Library.

**SATS Application:** Test of Glass Cockpit primary pilot-FMS interface comparing current-generation design Control Display Unit (CDU) and multi-windows CDU based on graphical user interface techniques in regard to pilot training time.

**Summary:** Flight Management System (FMS) pilot training experience study was conducted measuring the time taken to train 16 pilots with no previous with glass cockpit FMS. The evaluation focused primarily on the comparison of primary pilot-FMS interface comparing a current-generation design to a multi-windows CDU based on graphical user interface techniques. Color flat-panel displays were used to represent the CDU. As such, this “soft” interface did not provide tactile feedback associated with real button interaction. The multi-windows design employed the use of color-coding on the emulated CRT of the CDU. Study was conducted in an aircraft simulator. Out of eight conducted tests only one showed a significant performance difference, which favored the graphical design. This area was a task employing navigation intercepts that appeared to produce better task mapping between the task requirements and the interface for the graphical CDU. All pilots experienced confusion with CDU abbreviations and acronyms. While CDU phrases appear understandable, they may not be meaningful (i.e. VNAV for vertical navigation, may not intuitively bring to mind the association “Climb, cruise, and descent data.” The combination of the less than optimum function hierarchy and the mismatch between ATC clearances and the pilots’ task to implement those clearances was the largest deficiency observed during this study. Findings: functions need to be

provided that directly support the pilots' operational tasks and a window or page hierarchy must be provided that offers a natural linking and tractability mechanism between these functions.

## **Data Link Information Distribution and Cockpit Information Display**

H. Paul Stough, III, H. P., Daniel B. Shafer, D. B., Schaffner, P., & Martzaklis, K. S. (2000). Reducing aviation weather-related accidents through high-fidelity weather information distribution and presentation. ICAS 2000 Congress, NASA Langley Research Center Technical Library.

**SATS Application:** Airborne-ground data link information systems and cockpit

presentation-real time weather and warning update capability

**Summary:** In February of 1997, the President announced a national goal to reduce the fatal accident rate for aviation by 80% within ten years. Weather has been identified as a causal factor in approximately 30% of all aviation accidents. In the early 1990s, a Cockpit Weather Information (CWIN) system was developed and evaluated by NASA. This paper proposes a more advanced data link information system, Aviation Weather Information (AWIN) and Weather Information Communications (WINCOMM). AWIN is comprised of weather products and information presentation (encompassing information from both onboard sensors and ground-based weather systems providing strategic and tactical information to users). WINCOMM includes the data links and supporting networks. Operators need more than just weather information for the in-flight decision process. Additional information needed includes aircraft capabilities, operator capabilities, and information on flight-path-relevant terrain obstacles, air space and traffic. NASA is focusing on national weather information systems for GA and transport aircraft. User-centered requirements for AWIN weather products, systems and components are being established. Aircraft-mounted, forward-looking technologies for weather hazard detection and remote satellite-based and ground-based sensor technologies are also being explored. It is anticipated that various forms of data link will

dominate future ground-to-air communications. In near term, systems will be augmented with digital information via VHF Data Link (VDL), using advances in internet technology (portable computers, cell phones) to become in-flight products. Information could be automatically over-laid on a glass cockpit display navigational panel to enhance the operator in-flight decision-making process.

Kauffmann, P., & Pothanun, K. (2000). Estimating the rate of technology adoption for cockpit weather information systems. *Old Dominion University Technical Publication*. Copyright 2000, Society of Automotive Engineers, Inc.

**SATS Application:** Market survey measuring the penetration rate of cockpit weather information systems in five aviation markets. Provides estimation of the sensitivity of financial acceptability of adoption of new data aviation information systems in transport, commuter, general aviation, business and rotorcraft communities. System also has strong cross over potential for automotive/trucking industry.

**Summary:** Viability of proposed cockpit weather systems are based on estimates for system investment costs, and recurring costs/savings in the transport, commuter and business markets. The business case for the rotorcraft and general aviation markets are sensitive to variation in costs and savings. However, survey responses indicated that safety is the primary motivation for the adoption of advanced cockpit weather systems. Survey respondents indicated that adoption rates for weather systems would be at the maximum market level within 25 years, achieving the 50% level within 8-11 years. In excess of 75% of respondents agreed or strongly agreed that both strategic and tactical information should be provided. The majority of those surveyed indicated that market success would require platform presentation of both historical and forecasted weather

data. For most segments, receiving information from satellite categories exceeded VHF ground preferences.

## **Augmented Situation Awareness Sensors**

Tarleton, N., Symosek, P., & Harman, R. (1998). PMMW/DPS/GPS integrated situation awareness systems. SPIE Conference on Enhanced and Synthetic Vision 1998, Orlando, FL *Society of Photo-optical Instrumentation Engineers (SPIE)*, 3364, 93-102.

**SATs application:** Development of real time augmentation sensor inputs into computer generated visual system for virtual "VFR" approaches in instrument conditions.

**Summary:** Integrating a Passive millimeter Wave (PMMW) camera, Global Positioning System (GPS) and a Differential Global positioning System (DGPS) enables piloted virtual visual approaches and landings in Cat III adverse weather conditions. A PMMW camera is being developed that is capable of displaying runway and associated environment in fog, smoke and clouds during both day and night conditions. This developmental camera operates at 89 GHz with an 18 inch aperture and 6 mrad perceived spatial resolution. The DPS Honeywell based Satellite Landing Systems (SLS) has a 30 nm range possessing 1.0 m lateral error, and 1.5 m vertical accuracy. This systems employs three GPS ground reference receivers, three fault tolerant Differential Correction Processors and two VHF D8PSK data-links or positional fault correction inputs. PMMW and DGPS integration provides the pilot with visibility and the DGPS provides precise navigational input. Neither technology is affected by weather conditions or day/night considerations. DGPS can be coupled with FMS. Display information is presented to the pilot through a HUD.

Muynck, R.J. and Khatwa, R. (1999). Flight simulator evaluation of the safety benefits of terrain awareness and warning systems. *National Aerospace Laboratory (NLR) report NLR-TP-99379*, Amsterdam: The Netherlands.

**SATS Application:** Augment warning system, instrument design, and visual display for terrain avoidance.

**Summary:** The report focuses on an investigation into the operational safety aspects of advanced Terrain Awareness and Warning systems (TAWS). The TAWS depicts graphical terrain information on a Navigation Display (ND) and provides predictive terrain collision alerting. Several ND terrain format displays were evaluated in an exploratory workstation study. A most preferred display format was determined and selected for further testing. The evaluation of the independent effects of terrain awareness information and predictive terrain alerting was completed. A Fokker 100 model Flight Simulator served as a test platform. Ten crews' performances were evaluated in fourteen scenarios involving flight in terrain-rich environments. Significant study conclusions include: flight crews vectored close to rising terrain were more comfortable with terrain display than without. Subjective ratings indicate that the terrain information increases spatial awareness and speed of detection of terrain critical situations, subjects reported that the visual terrain display was so compelling that it would be difficult not to use its information, particularly in high workload environments. Subjects reported that the system was easy to learn and use. Test subjects considered it essential that weather radar be added for depiction on navigation display (subjects disliked the spatial separation of navigation and weather information in the flight station).

Peter Hecker, P., Doehler, H., & Suikat, R. (1999). Enhanced vision meets pilot assistance. Society of Photo-optical Instrumentation Engineers (SPIE Proceedings), 3691, 125-135.

**SATS Application:** Onboard sensor evaluation to provide real world navigational update, assisting computer generated SVS presentation to pilot.

**Summary:** The combination of forward looking imaging sensors (such as DaimlerChrysler's HiVision millimeter wave radar), terrain data stored in on-board data



bases plus information transmitted from ground, and other aircraft via data link is used to provide improved situational awareness to the air crew. Results of flight testing were obtained from twin turbo prop aircraft (equipped with combination of INS and DPGS, three imaging sensors, standard TV, infrared, and HiVision radar) and a simulator evaluation using an Airbus A-340. Study produced sensor performance comparison correlating sensor characteristics of UV, Video, IR, LADAR, MMW, PBMMW, and PMMW. Testing revealed that the most promising sensor to provide external information for SVS interface was the 35 GHz HiVision mmw-radar (DaimlerChrysler).

Sutor, T., Bucureuss, S., Krieger, G., Wendler, M., & Witte, F. Sector imaging radar for enhanced vision (SIREV): Theory and applications. *Society of Photo-optical Instrumentation Engineers (Proceedings of SPIE)*, 4023, 292-297.

**SATS Application:** Real time navigation sensor update to proposed SATS synthetic vision and navigation systems

**Summary:** The demand for supplementing existing airborne radar systems by providing enhanced forward-looking capabilities has increased. Available systems are unable to satisfactorily achieve requirements for enhanced vision. Sirev (Sector Imaging Radar for Enhanced Vision) is under current development and testing at DLR. Conventional Doppler-imaging radar systems (SAR) suffer from a system-inherent visualization problem in the forward direction of the flight path. Existing non-doppler radar systems suffer from poor resolution and inherent operational difficulties stemming from the mechanical pivoting of the antenna. These difficulties prevent the current systems from serving as approach or landing aids for aircraft. A SIREV system that requires no mechanical pivoting and provides excellent forward resolution is proposed to eliminate the imaging gap in the forward direction. A combination of a SIREV sensor is proposed

to provide visual information for approach and landing while a SAR sensor is used to maintain a full circle radar sight of terrain.

Hellmenan, K., & Zachai, R. (1999). Recent progress in mm-wave-sensor system capabilities for enhanced (synthetic) vision. *Society of Photo-Optical Instrument Engineers (SPIE)*, 3691, 21-28.

**SATS Application:** Advanced sensor spans gap between optical sensors (infrared) and standard pulse radars to produce weather independent enhanced vision to support virtual VFR SATS operations.

**Summary:** This paper presents an update in the development of the Frequency Modulated Continuous Wave (FMCW) radar named HiVSION. HiVISION does not require the complex computing power of a Synthetic Aperture Radar (SAR), nor the high-power technology and bandwidth of pulse radars and importantly it does not require the complex electronic scanned antenna technique controlled by phase shifters. HiVISION's selected frequency requires a small and light-weight construction and enjoys minor influence from atmospheric conditions. The sensor has been tested both on fixed wing aircraft and high-speed ferries. Tests revealed that it provided good resolution with the ability to detect small objects such as birds and baggage. It provided excellent range and adequate azimuth resolution. The high information rate produces quasi-optical views which can be integrated easily into a HUD system.

## **Ground and Facility Operations**

Miller, J.L., Kerr, J.R., Gates, J., and Dickerson, T. (2000). Runway based infrared sensor for enhanced vision of approaching aircraft. *Society of Photo-Optical Instrument Engineers (SPIE)*, 4023, 154-160.

**SATS Application:** Ground personnel in many situations, especially located at facilities without a tower, need to know location of aircraft on approaching and on the airfield.

**Summary:** Paper summarizes a series of tests conducted to assess the performance of a fixed-field, infrared landing monitor system. The system evaluated is a staring, 3-5 micron mid-wave infrared (MWIR) An InSb infrared thermal imager was embedded in the centerline of an aircraft carrier flight deck. Tests included using SWIR, LWIR and MWIR. Specific enhancements were identified including the combined use of SWIR and MWIR in a wideband configuration of the InSb sensor. The ability of the infrared to image in all light levels, coupled with the increased ability to view through haze, smog, aircraft exhaust effluents and poor weather, result in a valuable enhanced sensor for landing operations.

Kato, T., Harigae, M., Tsujii, T., & Murata, M. (undated). Study of obstacle detection by integrating kinematic GPS with camera images for taxi guidance. Hardcopy - A04 CASI A04 (54p)/Microfiche - A01 CASI A01 (54p), ISSN 0452-2982

**SATs application:** Autonomous taxi at airfields without control, obstacle recognition and avoidance in limited visibility.

**Summary:** Achieving more efficient traffic control and improved flight safety in and around airports are among the most important issues for aeronautical engineering. It is essential to realize that free flight and its autonomous air traffic control requires a collision avoidance function in addition to a highly precise satellite navigation that enables airplanes to make instrument landings that meet the category III C standards.

Focusing on the taxi guidance phase in which an airplane taxis on a taxi-way, this report deals with how to build a navigation system which not only precisely measures the airplane's position, but also detects obstacles in its path to avoid collision. This system combines satellite navigation kinematic GPS (Global Positioning System) with camera images. Obstacle detection is achieved by calculating the difference between the information produced by the synthetic vision of the kinematic GPS and that produced by the camera images. This is the first study to propose this type of method for detecting obstacles. An aircraft, carrying this system, will be capable of autonomous taxi by detecting obstacles in its way and measuring their position (both in terms of distance and direction) relative to itself. To evaluate the actual performance of this method of detecting obstacles on a taxiway, a kinematic GPS/camera experimental system for an automobile was constructed and the test data off-line was analyzed. The results showed that the proposed navigation system was capable of detecting obstacles and measuring their relative position.

## **Navigation Aids/Instrumentation**

Teague, E.H. and Wilson, J. M. (1999). Low-cost inertial/GPS attitude and heading reference system (AHRS) for enhanced and synthetic vision (EV/SV) applications. *Society of Photo-Optical Instrumentation Engineers (SPIE)*, 3691, 58-69.

**SATS Application:** A low cost AHRS that combines a solid-state inertial sensor with advanced GPS capable of driving SVS displays supporting Tunnel in the Sky navigation.

**Summary:** Vehicles using vision enhancement systems require sensors that provide precise, real-time attitude and heading information. Existing attitude and heading reference systems (AHRS) meeting these performance requirements have traditionally been very expensive and unfriendly to price-sensitive applications/markets. This paper studies an AHRS system that is rugged, inexpensive and provides information with the accuracy and responsiveness needed to drive many enhanced/synthetic-vision displays, such as tunnel-in-the-sky guidance displays. This AHRS system is an augmenting solid-state rate gyro with high accuracy GPS attitude sensing. The accurate and drift-free GPS attitude measurements enable the use of new rate gyro technologies that are well suited for mass production and miniaturization. This entire Inertial/GPS AHRS sensor is made with all solid-state components that have high reliability over time and can be manufactured very inexpensively. Testing revealed that this Seagull Inertial/GPS prototype AHRS always agreed with an independent reference to within 2 degrees throughout the test. Testing was conducted on a testing platform, an instrumented yacht, and a Beech Bonanza aircraft.

## **Verification, Testing and Certification of Software and Hardware Equipment**

Butler, R. W., Carreno, V. A., Di Vito, B. L., Hayhurst, K. J., Holloway, C. M., Miner, P. S., Luttgen, C., & Munoz, C. (2000). NASA Langley's Research and Technology-Transfer Program in Formal Methods. *NASA Langley Research Center Report*, June 2000. Hampton, VA: NASA Langley Research Center.

**SATS Application:** Testing and verification of new enabling software and hardware equipment for SATS use.

**Summary:** Paper presents an overview of NASA Langley's research program in formal methods. The goals of NASA's formal method work is to make this procedure available for use on high integrity systems, while orchestrating the transfer of technology to U.S. industry by carefully designed demonstration projects and to use this technology to achieve NASA's goals in aeronautics development. Engineering is heavily dependent upon mathematical models and calculations to make judgments about designs. Formal methods provide software and hardware design mathematical analysis based on models. System verification is reduced to a calculation that can be checked by a machine. Verification has the ability to produce error-free designs by verifying design requirements down to the implementation of the software or hardware component, which is seldom performed in current practice. NASA Langley has developed three goals for the formal methods program: (1) develop formal methods technology suitable for a wide range of aerospace designs and (2) facilitate technology transfer by through joint projects between NASA and aerospace industries applying research to real systems, and finally (3) use adoption of formal methods procedure and technology transferred to industry to obtain the NASA goal of increased safety aviation safety, while achieving a decrease in air travel costs.

Schiefele, J., Damjanovic, D., & Kubbat, W. (2000). Certifiable database generation for SVS. Enhanced and synthetic vision 2000; Proceedings of the Meeting, Orlando, FL, Apr. 24, 25, 2000 (A00-41076 11-35). *Society of Photo-Optical Instrumentation Engineers (SPIE Proceedings)*, 4023, 52-62.

**SATs Application:** Development of certifiable methods for acquisition, validation, and processing of terrain, obstacle and airport databases to support aircraft Synthetic Vision Systems and autonomous navigation.

**Summary:** A review of prototype and production Synthetic Vision Displays (SVD) is presented, followed by stating the requirement for reliable sources of terrain, obstacle, navigation, and airport data for these displays. Jeppesen-Sanderson, Inc. and Darmstadt University of Technology are currently developing certifiable methods for acquisition, validation, and processing methods for terrain, obstacle, and airport databases. The acquired data will be integrated into a High-Quality Database (HQ-DB). This database will contain all information relevant for aviation applications. From the HQ-DB SVS relevant data is retrieved, converted, decimated, and adapted into a SVS Real-Time Onboard Database (RTO-DB). The process of data acquisition, verification, and data processing will be defined in a way that allows certification within DO-200a and new RTCA/EUROCAE standards for airport and terrain data. The open formats proposed for the HQ-DB and RTO-DB can be used to exchange data on different abstraction levels. The complete process will be established and evaluated for industrial usability. Finally, NASA-industry cooperation to develop industrial SVS products under the umbrella of the NASA Aviation Safety Program (ASP) is introduced. A key element of the SVS NASA-ASP is the development of methods for worldwide database generation and certification. Jeppesen will build three example airport databases that will be used in flight trials with NASA test aircraft.

Uijt de Haag, M., Jacob Campbell, J., & Gray, R. (2000). A terrain database integrity monitor for synthetic vision systems. Institute of Electrical and Electronic Engineers, IEEE, 0-7803-6395-7/00.

**SATS Application:** Improve safety of SVS and subsequent improvement of situational awareness of pilot reducing likelihood of Controlled Flight into Terrain (CFIT).

**Summary:** This research addressed a terrain database integrity monitor for Synthetic Vision Systems (SVS) in civil aviation applications. This study uses an integrity monitor that checks the consistency between the sensed terrain profile as computed from DGPS and radar altimeter data and the terrain profile as provided by the terrain databases. The purpose of the integrity monitor for an SVS is to provide the user with a warning in conditions when the SVS should be either used with caution or not used at all. A warning would be provided when an error is detected that would produce an unacceptable hazardous display of terrain information on the pilot's visual display system. Flight tests were performed in which radar altimeter and KGPS data were collected.

Helmetag, A., Smietanshi, G., Baumgar, M., Kubbart, W. (1999). From digital elevation model data to terrain depiction data. *Society of Photo-optical Instrumentation Engineers (SPIE proceedings)*, 3691, 116-124.

**SATS Application:** Technique to improve Terrain depiction quality in synthetic visually displayed systems.

**Summary:** Information on 3D displays is shown in a graphical format so it can be intuitively seized and processed by the pilot. Terrain depiction is a key element in SVS. Real time terrain depiction faces two requirements: recognition of synthetic environment characteristics, which is extremely demanding, and the number of rendered polygons which have to be minimized due to limitations of the real time image generation



performance. Visual quality can be significantly enhanced if equidistant data like Digital Elevation Model data (DEM) are vectorized. This study analyzed the advantages and the process used to vectorize digital terrain data. It was shown that vectorization increases visual quality of the terrain that has been already decimated using a process termed Triangulated Irregular Network (TIN). This network produces vectorized high quality data ready for Real Vector Depiction.

Wiesemann, T., Schiefele, J., May, L., Mehler, F., & Kubbat, W. (2000). Controlled decimation of digital elevation data and subsequent in-flight verification. Society of Photo-Optical Instrument Engineers (SPIE), 4023, 40-51.

**SATs application:** Provides data for verification of real-time 4D Synthetic Vision systems enabling CAT I like approaches in CAT III conditions.

**Summary:** Today' and tomorrow's real-time aviation applications require extremely accurate and reliable databases. Common TAWS implementations such as EGPWS or integrated navigation systems such as Dasa's Integrated Navigation and Flight Guidance System super (16) depend essentially on terrain elevation databases. Regarding these applications, the resolution, accuracy, and precision of available data are of primary concern. By comparison, 4D Synthetic Vision Systems (SVS) require performance optimized terrain models for a real-time visualization. The content of these databases require reduction and accessibility in a real-time format. In 4D SVS, safety critical terrain databases are essential. Even higher accuracy is required for more demanding tasks such as low-level flights, precision approaches, or landings. In this paper a process is described to accomplish the contradictory demands of accuracy and visualization performance. The complexity of hi-resolution terrain models is reduced to enhance the rendering performance. Two different decimation approaches are explained and the resulting terrain

database is described. Each representation of the generated elevation shapes comprises a coarser quantity of the input data. A statistical error analysis of resulting altitude errors is presented. The presented results represent both offline verification with highly accurate databases and a comparison with altimeter data measured by airplane sensors during flight trials. To evaluate the different databases and to examine specific terrain resolutions, multiple flight trials were performed.

Simard, P., Link, N. K., & Kruk, R. V. (2000). Evaluation of algorithms for fusing infrared and synthetic imagery. Society of Photo-Optical Instrument Engineers (SPIE), 4023, 127-138.

**SATs Application:** Algorithms used for verification and support of airborne Enhanced/Synthetic Vision System (ESVS). Visual systems that can be adapted for SATs aircraft.

**Summary:** Algorithms for image fusion were evaluated as part of the development of an airborne Enhanced/Synthetic Vision System (ESVS) for helicopter Search and Rescue operations. The ESVS will be displayed on a high-resolution, wide field-of-view helmet-mounted display (HMD). The HMD full field-of-view (FOV) will consist of a synthetic image to support navigation and situational awareness, and an infrared image inset will be fused into the center of the FOV to provide real-world feedback and support flight operations at low altitudes. Three fusion algorithms were selected for evaluation against the ESVS requirements. In particular, algorithms were modified and tested against the unique problem of presenting a useful fusion of information from high quality synthetic images with questionable real-world correlation and highly correlated sensor images of varying quality. A pixel-averaging algorithm was selected as the simplest way to fuse two different sources of imagery. Two other algorithms, originally developed for real-time

fusion of low-light visible images with infrared images, (one at the TNO Human Factors Institute and the other at the MIT Lincoln Laboratory) were adapted and implemented. To evaluate the algorithms' performance, artificially generated infrared images were fused with synthetic images and viewed in a sequence corresponding to a search and rescue scenario for a descent to hover. Application of all three fusion algorithms improved the raw infrared image, but the MIT-based algorithm generated some undesirable effects such as contrast reversals. This algorithm was also computationally intensive and relatively difficult to tune. The pixel-averaging algorithm was simplest in terms of per-pixel operations and provided good results. The TNO-based algorithm was superior in that while it was slightly more complex than pixel averaging, it demonstrated similar results, was more flexible, and had the advantage of predictably preserving certain synthetic features which could be used support obstacle detection.

Friedrich, A., Raabe, H., Schiefele, J., & Doerr, K. (1999). Airport-databases for 3D synthetic-vision flight-guidance displays database design, quality-assessment and data generation. *The International Society for Optical Engineering (Proceedings of SPIE)*, 3691, 108-115.

**SATs Application:** Proposal for establishment of methods for creation, collection and certification of airport, terrain and navigational data in support of highly reliable 3D SVS displays for pilots. Support virtual VFR SATS approaches to GA airfields.

**Summary:** Remote sensing and digital photogrammetry provide a means to produce large volumes of airport terrain and obstacles with a high degree of spatial resolution and accuracy in substantially shorter timeframes compared to traditional surveying. The concept of a Geographical Information System (GIS) based High-Quality-Database (HQDB) was created at the Technical University Darmstadt (TUD). To enable database

certification, quality-assessment procedures according to ICAO Annex 4, 11, 14 and 15 and RTCA DO-200A/EUROCAE ED76 were established in the concept. The concept was tested with the Stuttgart/Germany airport. The results proved that the final accuracy was within the accuracy specification defined by ICAO Annex 14. As spatial resolution for satellite based sensing systems continues to decrease, it is possible in the future to generate airport and terrain databases from orbit.